Ecological Modelling 403 (2019) 23–34

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Modelling past, present and future Ecosystem Services supply in a protected floodplain under land use and climate changes

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ARTICLE INFO

Keywords:
Protected areas
Ecosystem services trade-offs
InVEST model
Carbon storage
Water flow regulation

ABSTRACT

The understanding of protection initiatives' effects on the delivery of Ecosystem Services (ESs) is of paramount importance to attain sustainable management in Protected Areas (PAs). Protected floodplains provide important ESs to local populations such as water flow regulation and climate regulation through carbon storage. This study investigates the effects of biodiversity protection initiatives (i.e. declaration of Protected Areas – PAs) and the related spatio-temporal land use/land cover (LULC) changes on ecosystem services (ESs) in the Nature Reserve of Paul do Boquilobo – NRPB (Central Portugal). Special focus was made on climate mitigation (i.e. carbon storage and sequestration) and water-related (flood mitigation, water regulation and supply) ESs. The analysis was performed using InVEST model. Three dates of past LULC conditions were considered in the analysis (1967, 1990 and 2015). Moreover, two future alternative LULC scenarios for 2050 were designed (a "Business"- BUS and a "Naturalization"- NAT scenario). The BUS scenario considers a LULC distribution towards high productive agricultural systems, considering only a restricted central core of natural areas, while the NAT scenario considers full coverage of natural areas. The two future extreme LULC scenarios were analyzed considering both no climate change and climate change effects on water-related services based on the pessimistic rcp8.5 climatic scenario. The results showed that PA declaration of NRPB after 1980 increased carbon storage-sequestration and flood mitigation (higher water storage, lower recharge and runoff). The analysis of future LULC scenarios demonstrated that the complete renaturing in combination with climate change (reduction of precipitation, increase of temperature) may lead to severe reduction of recharge and runoff. These results indicate that conflicts may appear between specific water regulation services by the application of PA initiatives in places where groundwater resources are limited or minimum ecological flows in surface waters are difficult to be preserved.

1. Introduction

The declaration of Protected Areas (PAs) is one of the most important instruments to control the loss of biological diversity and to safeguard threatened species and ecosystems all over the world. PAs are designed to protect local and regional biodiversity from anthropogenic pressures and impacts (Margules and Pressey, 2000). According to the Protected Planet Report (UNEP-WCMC and IUCN, 2016), PAs cover almost 15% of the world's terrestrial and inland waters, nevertheless their relevant global extension is likely to increase in the future, due to the increased awareness about their importance in developing countries. When properly managed, PAs may play an important role on poverty alleviation and sustainable development of local populations (Naughton-Treves et al., 2005; Andam et al., 2010; Canavire-Bacarreza and Hanauer, 2013). Moreover, the management of PAs requires a long-term political view and financial commitments that are often not attained (Bruner et al., 2004; Hockings et al., 2006).

Biodiversity and ecosystem services (ESs) are intrinsically related, while PAs are fundamental assets that support the flows of a wide set of valuable services and particularly those that are not directly marketable, whose maintenance can be justified by their functional values (Millennium Ecosystem Assessment, 2005). Regulating services are often involved in relationships (trade-off and/or synergies) with other ESs (Bennett et al., 2009) and for this reason can be considered as suitable indicators for assessing ecological resilience (Bennett et al., 2005). However, their environmental value is frequently ignored, as it

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https://doi.org/10.1016/j.ecolmodel.2019.04.019
Received 30 November 2018; Received in revised form 10 March 2019; Accepted 27 April 2019
Available online 02 May 2019
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is not incorporated in the market dynamics (Turner and Daily, 2008). For this reason, severe losses of regulating services were observed when provisioning services were boosted, particularly on floodplain environments (Jia et al., 2014; Palomo et al., 2014; Gaglio et al., 2017a).

Floodplains host ecotones with an exceptional biological diversity, particularly when high-levels of spatial and temporal heterogeneity is present (Ward et al., 1999; Ward and Tockner, 2001). The water-terrestrial interface supports a large number of species, which are benefited from intermediate disturbance conditions (Crandall et al., 2003) regulated by flood dynamics (Tockner and Ward, 1999; Thomaz et al., 2007). Floodplains also perform regulating functions of great importance for the surrounding environment. They can significantly regulate floods' impact through water absorption and nutrients retention (Weng et al., 2003; Forshay and Stanley, 2005; Hoffmann et al., 2009), avoiding damages to human settlements and protecting groundwater quality.

Due to their high productivity (Güneralp et al., 2014), floodplain ecosystems can store significant amounts of carbon in soil and living biomass, playing a role in the climate change mitigation and being an important carbon sink for other terrestrial ecosystems (Robertson et al., 1999; Cartisano et al., 2013). Climate change is expected to exacerbate not only biodiversity changes (Sala et al., 2000; Araújo and Rahbek, 2006) but also the capacity of ecosystems to provide goods and services (Pecl et al., 2017), especially in the Mediterranean regions (Sala et al., 2000). Climate change is expected to potentially accelerate changes in species distribution (Araújo and Rahbek, 2006), reshuffling the geographic distributions of plant and animal species world-wide (Parmesan and Yohe, 2003). However, even if current estimates in biodiversity changes are very variable (Bellard et al., 2012), there is the need to improve knowledge about potential changes in biodiversity (Sala et al., 2000) and ES provision (Pecl et al., 2017) in order to be prepared for adapting management decisions able to address those changes (Maragno et al., 2018).

The aim of this study is to assess the effects of PA designation on spatial and temporal changes of regulating ESs (climate regulation based on carbon storage, water supply and water regulation) in a protected floodplain of Central Portugal: the Nature Reserve of Paul do Boquilobo (NRPB). In order to describe the ES flow before and after the establishment of PA in 1980 in this study area, three dates with their respective land use/land cover (LULC) maps were considered: 1960, 1990, and 2015. Moreover, future projections of land use and climate change to 2050 were combined with the aims a) to simulate the response of ESs to such modifications using two InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) models, namely the "Carbon Storage and Sequestration" and the "Seasonal Water Yield" models (Sharp et al., 2016) and b) to use the simulation results to evaluate future management measures for the study area. It worths mentioning that unlike the Seasonal Water Yield model, the formulas of Carbon Storage and Sequestration model are not climate-dependent. Therefore, the outcomes regarding the climate change effects concern only the water budget and its related services.

2. Data and methods

2.1. Study area

The Nature Reserve of Paul do Boquilobo (NRPB) (39°23′N and 8°32′W) is a natural floodplain of 817 ha, with an altitude between + 15 m and + 32 m a.s.l. It is located in the catchment area of Almonda River, a tributary of Tagus River, in the municipality of Torres Novas and Golegã (district of Santarem, central Portugal) (Fig. 1). The annual precipitation is about 713 mm yr^{-1}, and the area can be classified within the Dry Sub-humid (C1) category according to the Thornthwaite moisture classification (Feddema, 2005). The Tagus valley has been subjected to land reclamation works during the last decades of the 19th Century, with the aim to gain new arable land. To counterbalance the impact of human pressures on this environment, the NRPB was declared PA based on the National Law No. 198/80 of July 24 (green area in Fig. 1). This area hosts one of the most important communities of herons in Portugal and is a popular spot for wintering water birds such as ducks, coots and waders. It is the only national reproductive site for *Aythya ferina*, one of the main sites for refuge species such as *Anas penelope* and *Anas clypeata* and one of the few potential sites for nesting of *Chlidonias hybrid*. In addition, several fish species like the endemics *Chondrostoma oligolepis* and *Iberochondrostoma lusitanicum* use the reserve for reproduction (ICNF - Instituto da Conservação da Natureza e das Florestas, 2005). The NRPB is currently characterized by riparian corridors, with predominance of *Salix*, *Populus* and *Fraxinus* species. In favor of protecting such biodiversity assets, the Forestry and Nature Conservation Institute (ICNF) implemented a Management Plan following the IUCN directives, where a core area of total protection was established (core PA in Fig. 1), while the part of NRPB not belonging to the core PA was considered as areas of partial or complementary protection. NRPB plays an important hydrologic role for all the surrounding ecosystems. During the wet periods, the area functions as an area of water retention during the frequent floods of the Almonda river, protecting the surrounding croplands. During dry periods, the NRPB provides valuable water supply for irrigation by recharging local aquifers (Baptista and Santos, 2016).

2.2. LULC maps and future LULC scenarios

The LULC maps for 1967 and 1990 are products of the "Map of agricultural and forested land of Portugal" (1:25000 scale with 12.5 m resolution), which were elaborated by the Survey and Planning Service of the Ministry of Economy of Portugal for the respective years. The 2015 map was generated from aerial orthophotometry 1:5000 scale in association with the Habitat map {drawn according to the Habitat Directive of the European Union 92/43/EEC (European Commission, 1992)}, after correction using data from field surveys, delivering a 2.5 m resolution. All the maps were harmonized according to a common LULC classification, as reported in Table 1. An additional classification for the riparian forests was also carried out since fast growth rates are reported for these ecosystems (or for the species that compose them) (Giese et al., 2000; Rheinhardt et al., 2012), and thus they were further classified in "young" and "mature" (see definitions in Table 1). Moreover, two future alternative LULC scenarios for 2050 were developed: a "business scenario - BUS" and a "naturalization scenario - NAT". The two future scenarios were projected reclassifying the 2015 scenario, which was used as baseline.

The BUS scenario was obtained reclassifying all the private lands of 2015 scenario to croplands. It was assumed that all the private lands inside NRPB will be exploited in such way to maximize market-ESs (i.e. for food and fiber provision) and consequently the income of the owners (i.e. though conversion to irrigated crops, olive groves and poplar plantations), while the natural evolution of ecosystems is guaranteed inside the core protected area (as proposed in the Management Plan of Instituto da Conservação da Natureza e das Florestas - ICNF). The recommendations of the Management Plan would guarantee the protection of the ecological evolution process towards climax conditions inside the total protected area. Furthermore, the presence of a cork oak forest area would be also promoted on the lands belonging to the state outside the core area, as traditional landscape feature supported by the management Plan (Santos et al., 2016).

The NAT scenario was projected reclassifying all the cropland mapped in 2015 scenario to natural land coverages. The projection assumes that all the private lands will be purchased by the NRPB under the premises of the Management Plan provisions that are currently in place (ICNF - Instituto da Conservação da Natureza e das Florestas, 2005). Thus, a process of landscape naturalization in most of the Nature Reserve will occur since it will be owned by the government. Larger areas would undergo naturalization processes, except for olive groves in

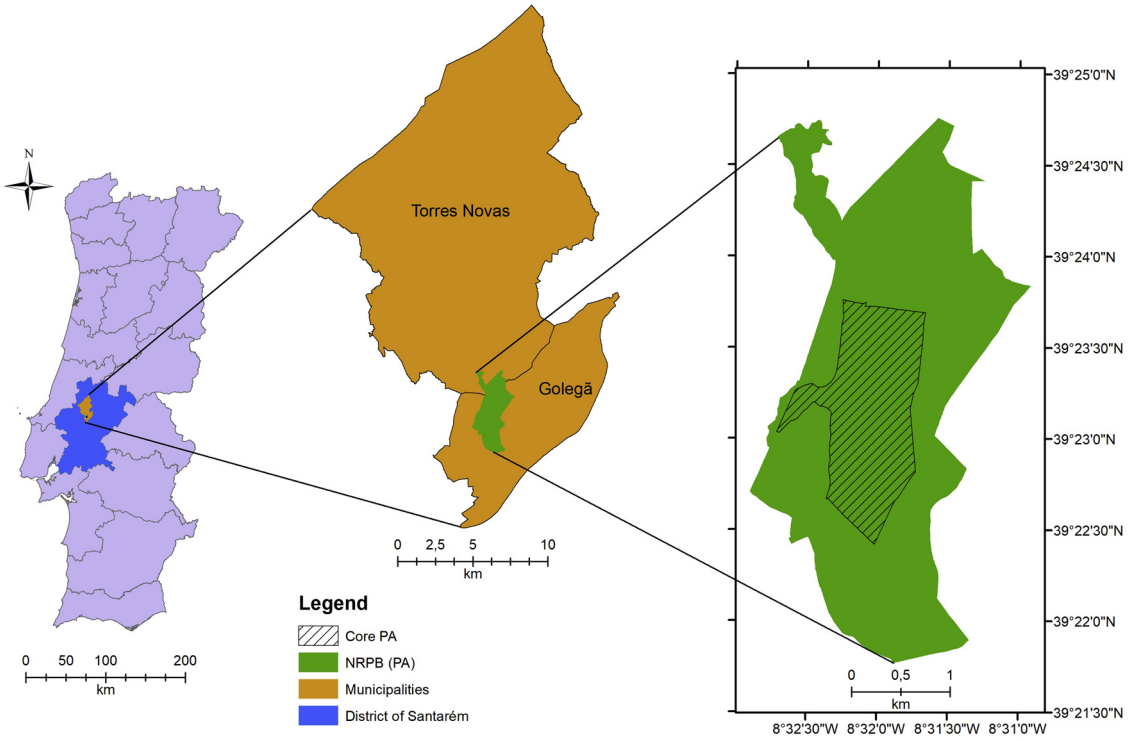

Fig. 1. Location of Natural Reserve of Paul do Boquilobo (NRPB) in Portugal and boundaries of PA.

the Northern part of the Reserve. Croplands and poplar plantations would be replaced by Mediterranean grasslands, and oak forests would be maintained in the western part to preserve traditional landscape. Riparian forest would expand from buffer zones nearby the watercourses and the existing young riparian forest would evolve to climax stage (i.e. mature riparian forest). It was assumed that such evolution could occur in ˜30 years (˜2050). Thus, some "young riparian forest" areas from the 2015-scenario will evolve to "mature" stage in future-scenarios considering that no human impacts or intervention affects them.

The aforementioned two future LULC scenarios describe the two opposite extreme gradients that define the maximum range of LULC changes in the study area and consequently the respective two extreme possible trends of ESs changes.

2.3. Climate data

For the past and future scenarios without climate change, the climate raster data of the period ˜1950–2000 of mean monthly precipitation (*P*), minimum, mean and maximum temperature (*Tmin, Tmean, Tmax)* from WorldClim database (http://worldclim.org) (Hijmans et al., 2005) and reference evapotranspiration ET_o of ASCE-standardized method (Allen et al., 2005) for short reference crop (clipped grass) from Aschonitis et al. (2017) were used (data of ˜1 km resolution).

The mean monthly rasters data of ET_o, *Tmin, Tmean, Tmax* and *P* were also used to build a simplified ET_o model for the study area $\{ET_o = 6.3837Tmean - 0.6466P + 2.5109(Tmax\text{-}Tmin),\ R^2 = 0.99,\ p < 0.001\}$. This model was used to build rasters of future ET_o

Table 1
LULC classification of LULC maps for 1967, 1990, 2015 and 2050.

Land cover type	Description
Irrigated crops	Land cultivated with annual crops that is under irrigation (mainly corn)
Aquatic	Permanent wetlands and Almonda river
Eucalyptus plantation	Plantations of *Eucalyptus globulus*
Oak forest	Forest dominated by *Quercus suber*
Pasture/grassland	Lands covered by permanent herbaceous species
Poplar plantation	Plantations of *Populus sp.*
Young riparian forest	Established riparian forest with dominant trees age between 25 and 50 years old. Predominance of *Populus. sp., Salix sp., Fraxinus sp.*
Urban	Railroads and farm buildings
Olive groves	Plantations of *Olea europea*
Rice cultivation	Land cultivated with *Oryza sativa*
Orange cultivation	Plantations of *Citrus sinensis*
Non-irrigated crops	Land cultivated with annual crops without irrigation (mainly wheat)
Figs cultivation	Plantations of *Ficus carica*
Vineyards	Plantation of *Vitis vinifera*
Oak and Pine forest	Forest dominated by *Quercus suber* and *Pinus pinaster*
Oak and young riparian forest	Forest dominated by *Quercus suber* and riparian species (25-50 years old)
Oak and holm oak forest	Forest dominated by *Quercus suber* and *Quercus ilex*
Mature riparian forest	Riparian forest with dominant trees older than 50 yr. Trees increased in canopy, basal area and stem density. Tree height and canopy show higher degree of differentiation
Sclerophyllous vegetation	Land covered by sclerophyllous woody vegetation that do not meet the forest or permanent crop definitions

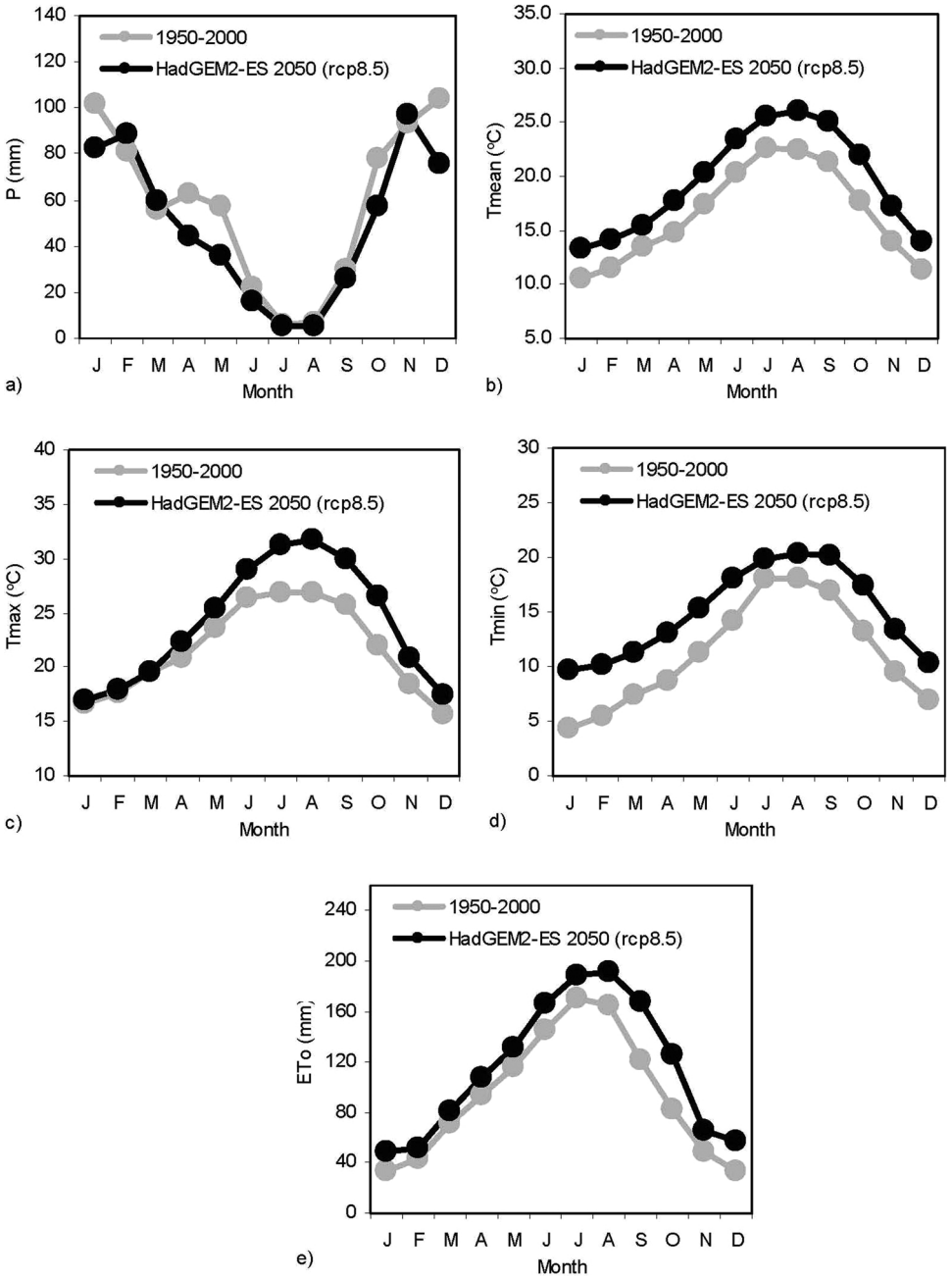

Fig. 2. a) Mean monthly precipitation *P*, b) mean monthly temperature T_{mean}, c) mean monthly maximum temperature *Tmax*, d) mean monthly minimum temperature *Tmin* and e) mean monthly evapotranspiration ET_o, of 1950–2000 and 2050 for the rcp85(HadGEM2-ES) climate change scenario.

conditions considering the *Tmin, Tmean, Tmax* and *P* raster values of 2050 estimated by the HadGEM2-ES model (Collins et al., 2008) for the rcp85 scenario (worst scenario of greenhouse gas emissions). The difference between the past and the future conditions for the *P*, *Tmean*, *Tmax*, *Tmin* and ET_o are given in Fig. 2a–e, respectively.

2.4. InVEST model

The effects of protection initiatives on regulating ESs was analyzed using InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) Version 3.3.3 package (Sharp et al., 2016). The model simulated a) climate regulation based on carbon storage and sequestration (model of Carbon storage and sequestration: Climate regulation), and b) water supply and water regulation (model of Seasonal water yield), using the three LULC maps of NPRB that correspond to the dates 1967, 1990 and 2015 plus the "business" and "naturalization" LULC future scenarios for 2015 and 2050. The models were run for each past date and future projections, to allow a comparison of the outputs. Since the NRPB was declared PA in 1980, the changes in LULC and regulating ESs occurred between 1967 and 1990 period can assess the first consequences of the protection initiative, while those occurred during between 1990 and 2015 can estimate the effects of its management. Similarly, the comparisons of the future LULC scenarios (BUS and NAT) with or without climate change versus the past scenarios can assess the effects of future LULC designation and climate change on ESs. The main data sources used for the simulations are presented in Table 2.

2.4.1. Climate regulation

Carbon sequestration is the mechanism through which natural ecosystems withdraw carbon from the atmosphere that is stored in their

Table 2
Data sources used for the simulations of InVEST model scenarios.

Data	Source
LULC map of 1967	Map of agricultural and forest lands of Portugal. 1967. Recognition and Planning Service. Ministry of Economy of Portugal
LULC map of 1990	Map of agricultural and forested land of Portugal. 1990. Recognition and Planning Service. Ministry of Economy of Portugal
LULC map of 2015	Habitat map corrected by the authors based on field surveys
LULC maps of 2050, BUS and NAT scenarios	Management Plan of ICNF (2005)
Carbon content, MAI, shoot-to-root ratio	Portuguese national inventory report on greenhouse gases, 1990-2012 (Pereira et al., 2014) (Table S.1 in Supplementary Material)
Maps of monthly reference crop evapotranspiration (mm)	Aschonitis et al. (2017) (https://doi.pangaea.de/10.1594/PANGAEA.868808, http://esrn-database.org/gis-data.html)
Maps of monthly precipitation (mm) and temperature (°C) for current and future scenarios	(Hijmans et al., 2005; Fick and Hijmans, 2017) WorldClim (http://www.worldclim.org/). Future scenarios of HadGEM2-ES for rcp8.5 are also provided by WorldClim database as elaborated rasters.
Digital Elevation Model (DEM) (m)	SRTM of 90 m resolution (http://srtm.csi.cgiar.org/)
Map of SCS soil hydrologic groups	(Atlas of soil water) European Data Portal (https://www.europeandataportal.eu/data/it/dataset/e66eced9-8319-4584-8038-cf9b05e0e207)
Curve Number (CN)	(NRCS, 1986)
Crop Factor (Kc)	InVEST database, FAO (http://www.fao.org/docrep/X0490E/x0490e0b.htm)
Average numbers of events per month (Santarém weather station, 1961–1990)	https://www.yr.no/place/Portugal/Santar%C3%A9m/Vale_de_Estacas/statistics.html

living and dead biomass of the soil. The amount of carbon stored in natural ecosystems can significantly mitigate climate change due to the excess of carbon dioxide concentration in the atmosphere. The amount of carbon stored and sequestered based on the different LULC and climate scenarios was estimated using the tool "Carbon Storage and Sequestration: Climate Regulation" of InVEST biophysical model (Sharp et al., 2016). The tool estimates the amount of carbon currently stored in a landscape and the amount of carbon sequestered over time, by integrating four carbon pools (aboveground biomass, belowground biomass, soil, dead organic matter) with land cover maps. Input data for carbon pools is provided in Table S1 (Pereira et al., 2014). Optionally, the model can provide monetary values of sequestered carbon for the period 2015 − 2050. The computation of monetary value (Net Present Value) considered a social cost per metric ton of carbon of 220US$ (Moore and Diaz, 2015) and a market discount rate in price of carbon of 7% (as suggested by the model). Values for terrestrial carbon pools were obtained from the Portuguese national inventory (Pereira et al., 2014), except for soil carbon content in grasslands, which was derived from local survey data. No value for carbon storage and sequestration was attributed to water ecosystems, despite the important role of the marsh in storing such a resource. When no direct correspondence was evident between own and national inventory LULC classifications, the values were selected from the most coherent class. Carbon storage values for "mixed" LULC classes were calculated by combining the most representative habitats. For example, the carbon storage of "young riparian forest" was calculated as the weighted average of "*Quercus* spp." (50%) and "Other broadleaf" (25% Poplar + 25% Willow). Aboveground and belowground carbon content of "mature riparian forest" were calculated by considering the Mean Annual Increment (MAI) of total living biomass, expressed as $m^3\,ha^{-1}$. These values were converted in Mg C ha^{-1} considering the gravity weight (t m^3) of the respective species (*Quercus spp.* = 0.85, *Poplar spp.* = 0.85 and *Willow spp.* = 0.75) and a default carbon fraction of 47% of biomass (as suggested by IPCC, 2006 guidelines). Carbon content was therefore allocated in above and below ground biomass pools, according to the shoot-to-root ratio of the respective LULC types. Both MAI and shoot-to-root ratio for forest type were also provided by Pereira et al. (2014).

2.4.2. Water regulation and supply

Natural systems can regulate hydrological flows by retaining water amounts in soil and groundwater, affecting evapotranspiration and infiltration. The water regulation services refer to the regulation of water flows on earth surface for maintaining the normal conditions in the watershed, while the water supply service is related to the infiltration, retention and storage of water in streams, lakes and aquifers (De Groot et al., 2002). The "Seasonal Water Yield" tool of InVEST model was used to analyze the water budget of RNPB. This model computes spatial indices that quantify the relative contribution of a land parcel to the generation of both base flow and quick flow, integrating the calculation of punctual water yield with the position of each pixel on the landscape (Sharp et al., 2016). The model requires a set of spatially explicit inputs, describing climate, soil, topography and biophysical factors (Table 2). It provides outputs for local recharge, actual evapotranspiration and runoff, computed on an annual time scale but using monthly values. Moreover, the map of "Soil Conservation Service (SCS) runoff Curve Number" (CN) was processed in ArcGIS 10.3 (ESRI) to obtain the contribution of soil to retain excess water, calculated as following (NRCS, 1986):

$$Smpr = \frac{25400}{CN} - 254$$

where *Spmr*: is the potential maximum soil moisture retention after runoff begins (mm) and *CN* is the curve number (dimensionless) for a specific hydrological soil group and LULC type. The *Spmr* represents the ability of soil to retain water while *CN* represents a measure of the capacity of the different land use/land cover and soil types to generate rainfall runoff (USDA – SCS, 1972). *CN* value depends on ground coverage, soil type and topography. Regions generating more runoff are assumed to generate greater flood risk (Maragno et al., 2018). The *Spmr* can be a suitable proxy for water flood mitigation (e.g. Chen et al., 2014).

3. Results

3.1. LULC changes

The LULC composition of the reserve suffered significant changes during time even after the PA classification decree (Table 3). During 1967, the landscape of NRPB was predominantly devoted to agricultural activities, where natural environments were almost absent. Pastures were located mainly in the central areas of the reserve and accounted for 18.9% of the total area. Rice fields were present on a large part of the naturally flooded areas, and irrigated crops were the most abundant LULC class.

After the PA classification decree, a permanent wetland was created to provide new habitats for aquatic and terrestrial species. This led also to the development of riparian forest ecosystems surrounding the wetland and along the course of the Almonda river, as evident in

Table 3
LULC patterns for 1967, 1990, 2015 and the two LULC scenarios to 2050. Values are expressed in both absolute (ha) and relative (%) values. Relative variations (var %) from the previous date of analysis are also reported.

	1967		1990			2015			2050 BUS			2050 NAT		
LULC type	Area	%	Area	%	var%	Area	%	var%	Area	%	var%	Area	%	var%
Irrigated crops	310.25	38.00%	347.25	42.50%	11.93%	417.74	51.20%	20.30%	532.56	65.20%	27.49%	0	0.00%	−100.00%
Aquatic	3.48	0.40%	52.55	6.40%	15.82%	66.83	8.20%	4.11%	66.83	8.20%	0.00%	66.83	8.20%	0.00%
Eucalyptus plantation	0	0.00%	4.24	0.50%	1.37%	1.1	0.10%	−0.90%	1.1	0.10%	0.00%	0	0.00%	−0.26%
Oak forest	31.27	3.80%	27.8	3.40%	−1.12%	30.99	3.80%	0.92%	26.86	3.30%	−0.99%	20.64	2.50%	−2.48%
Pasture/grassland Past	154.15	18.90%	5.29	0.60%	−47.98%	124	15.20%	34.19%	34.83	4.30%	−21.35%	423.83	51.90%	71.77%
Poplar plantation	11.5	1.40%	0	0.00%	−3.71%	14.76	1.80%	4.25%	40.11	4.90%	6.07%	0	0.00%	−3.53%
Young riparian forest	0	0.00%	86.09	10.50%	27.75%	140.88	17.30%	15.78%	10.39	1.30%	−31.24%	145.69	17.80%	1.15%
Urban	9.92	1.20%	9.32	1.10%	−0.19%	8.49	1.00%	−0.24%	8.49	1.00%	0.00%	8.49	1.00%	0.00%
Olive groves	80.56	9.90%	12.19	1.50%	−22.04%	11.77	1.40%	−0.12%	11.77	1.40%	0.00%	10.16	1.20%	−0.39%
Rice cultivation	173.87	21.30%	179.8	22.00%	1.91%	0	0.00%	−51.78%	0	0.00%	0.00%	0	0.00%	0.00%
Orange cultivation	9.99	1.20%	3.21	0.40%	−2.19%	0	0.00%	−0.92%	0	0.00%	0.00%	0	0.00%	0.00%
Non-irrigated crops	20.06	2.50%	1.78	0.20%	−5.89%	0	0.00%	−0.51%	0	0.00%	0.00%	0	0.00%	0.00%
Figs cultivation	11.49	1.40%	0.16	0.00%	−3.65%	0	0.00%	−0.05%	0	0.00%	0.00%	0	0.00%	0.00%
Vineyards	0	0.00%	39.1	4.80%	12.60%	0	0.00%	−11.26%	0	0.00%	0.00%	0	0.00%	0.00%
Oak and Pine forest	0	0.00%	0.44	0.10%	0.14%	0	0.00%	−0.13%	0	0.00%	0.00%	0	0.00%	0.00%
Oak and young riparian forest	0	0.00%	12.88	1.60%	4.15%	0	0.00%	−3.71%	0	0.00%	0.00%	0	0.00%	0.00%
Oak and holm oak forest	0	0.00%	0.38	0.00%	0.12%	0	0.00%	−0.11%	0	0.00%	0.00%	0	0.00%	0.00%
Mature riparian forest	0	0.00%	0	0.00%	0.00%	0	0.00%	0.00%	83.6	10.20%	20.01%	140.91	17.30%	33.73%
Sclerophyllous vegetation	0	0.00%	34.04	4.20%	10.97%	0	0.00%	−9.80%	0	0.00%	0.00%	0	0.00%	0.00%
	816.5	100%	816.5	100%		816.5	100%	0.00%	816.5	100%		816.5	100%	

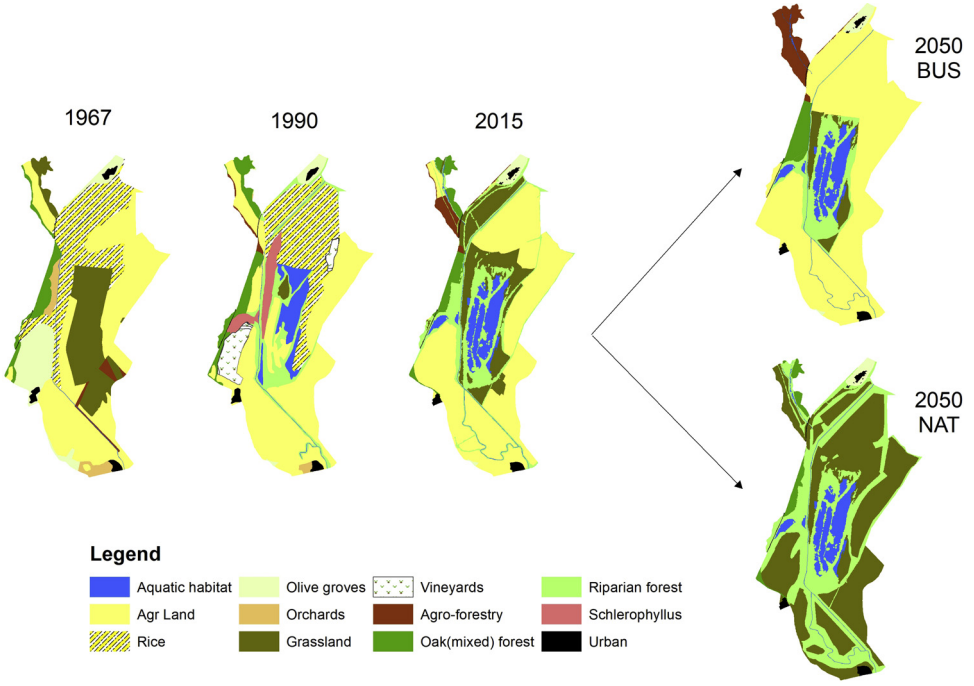

Fig. 3. LULC maps for 1967, 1990, 2015 and for two future LULC (BUS and NAT) scenarios to 2050.

1990 map (Fig. 3). However, agricultural activities maintained with the growing interest and spread of maize crops.

In 2015, due to the management decision of acquiring property, permanent aquatic habitats covered the 8.2% of the total area as results of protection initiative aiming to the conservation of aquatic species. Many of these ecosystems were recorded as a valuable habitat according to 92/43/EEC Directive, including those corresponding to the habitat codes 3130, 3150, 3260, 3280, 3290 (Table S.2 in Supplementary Material).

Riparian forests increased up to cover the 17.3% of the NRPB in 2015, leading to the classification of three riparian habitats (no. 91B0, 92A0 and 9240). Mediterranean tall humid grasslands were also restored (no. 6420) together with pastures activities. Agricultural activities suffered a strong simplification with the complete loss of rice fields, non-irrigated crops, orchards and vineyards. Corn monocultures (irrigated crops) currently cover more than half of the NRPB.

As regards the BUS scenario of LULC changes in 2050, the irrigated crops were hypothesized to spread again up to 65.2% of the total area. Inside the area under total protection, permanent wetlands would be maintained, and young riparian forests would evolve to mature stages. Poplar stands would be planted over all the north-west part of the NRPB.

The projection performed according to the NAT scenario of LULC changes in 2050 would lead to complete agricultural abandonment except for few hectares covered by olive groves. The abandoned cropland would evolve to Mediterranean grasslands, which would cover the larger part or the Reserve. This scenario would lead to the maximum coverage with previously mentioned habitats included in 92/43/ECC

Table 4
Carbon storage and sequestration in NRPB in the dates considered. The Net Present Value was calculated only for future scenarios as described in Section 2.3.1.

	Tot C (Mg)	[2]Sequestered C (Mg)	[3]Mean Annual Seq C (Mg yr^{-1})	[4]Net Present Value (US$)
1967	51239.0			
1990	56602.4	5363.4	233.2	
2015	58244.3	1641.9	65.7	
[1]2050 BUS	62244.5	4000.2	160.0	313845.4
[1]2050 NAT	69060.1	10815.8	432.6	848577.6

[1] Without considering climate change.
[2] Sequestered carbon in comparison to the previous date. 2050 scenarios are compared with the 2015 scenario.
[3] Sequestered carbon between two dates divided by the number of years.
[4] Net Present Value is estimated only for 2050 scenarios in comparison to 2015.

Directive.

3.2. Climate regulation services

The amount of stored carbon increased in time as a consequence of LULC changes occurred during 1965–2015 (Table 4) (Fig. 4). The period 1967–1990, during which the protection initiative started, unfold a large gain (+10.5%) of carbon stored into the ecosystems, despite the creation of wetlands in the core area. During 1990–2015, an additional but lower gain was estimated (+2.9%). In this period, the further increase of wetlands and irrigated crop areas was overcompensated by expansion of riparian habitats. Among the LULC classes, irrigated crops showed the highest contribution to carbon sequestration for all the three considered dates (39.8%, 40.5% and 47.3%, of the total stored carbon for 1965, 1990 and 2015, respectively).

Gains of C amount were also predicted in both future LULC scenarios (BUS and NAT) without climate change effects. Surprisingly, even the transition from 2015 to 2050 according to the "Business" scenario" would lead to a considerable C increase (+6.9%), with the contribution of irrigated crops being 56.4% of the total stored carbon. Despite the expansion of irrigated crops and the loss of riparian forests, the latter would switch to a mature stage (i.e. transition from "young riparian forest" to "mature riparian forest"), sequestering high amounts of C from the atmosphere. On the other hand, the transition from 2015 to 2050 according to the NAT scenario would lead to even larger carbon stock gain (+18.6%), with riparian forests and grasslands being the largest contributors to carbon sequestration (36.4% and 27.9% contribution for mature and young riparian forests, respectively and 32.4% contribution of grasslands of the total stored carbon).

The hypothesized net present values of future carbon sequestration (2015–2050), based on social cost of carbon emission, were assessed to be 313,845 US$ and 848,577 US$ for the BUS and NAT scenarios in total, respectively. This means that a value range of 534,732 US$ will depend on the selection of future LULC management plan (BUS or NAT) of the area.

3.3. Water regulation and supply

The effects of LULC changes on water budget distribution were evaluated for each date (1965, 1990, 2015) of the period 1965–2015 (Fig. 5, Table 5). Actual evapotranspiration *AET* and runoff were observed to be the most and less contributing water budget components, respectively, as expected in a flat and dry environment. However, the LULC changes that occurred over time slightly affected the water budget (Table 5) but with a decreasing trend of recharge and runoff accompanied by an increasing trend of *AET* in time, due the respective increase of *Spmr* indicating a better water retention and a better exploitation of water resources for covering evapotranspiration requirements. In fact, despite the loss of terrestrial areas, estimated values of total *Spmr* increased, as a consequence of the larger contributions of forests rather than arable land.

Considering the two LULC scenarios of 2050 (BUS and NAT) without climate change (Table 5, Fig. 5), it is observed that BUS scenario presents similar hydrologic responses (recharge, *AET*, runoff, *Spmr*) with the LULC responses of 1990 and 2015 LULC conditions. On the other hand, the NAT scenario shows an evident decrease of recharge and runoff and increase of *AET* due the evident increase of *Spmr* indicating that the NAT LULC conditions lead to even higher water retention and much better exploitation of water resources for covering evapotranspiration requirements.

Comparing the two LULC scenarios of 2050 (BUS and NAT) with climate change (Table 5, Fig. 6) with respective scenarios without climate change, it is observed reduction of -75.5% in recharge, -0.8% in *AET* and -35% in runoff for the BUS scenario and reduction of -98% in recharge, -2.2% in *AET* and −37.6% in runoff for the NAT scenario due to climate change. The projected -16.1% decrease of annual precipitation for 2050 according to rcp85 is the reason for the aforementioned reductions and especially for recharge and runoff. In the case of NAT scenario, the reduction of recharge and runoff is even higher compared to BUS due to the higher *Spmr*.

4. Discussion

4.1. Possible conflicts of ESs supply

The identification of conflicts and synergies among ESs gained an increasing interest in literature during the recent years, under the lens of environmental and PAs management. For example, Palomo et al. (2014) highlighted a positive contribution of Doñana National Park on maintaining ESs delivery, because of the isolation of PA with respect to the LULC changes which occurred outside. Onaindia et al. (2013) described the spatial congruence of biodiversity, carbon storage and water flow regulation, arguing that biodiversity conservation would ensure the provision of regulation services by the maintenance of native forest ecosystems. Synergy between biodiversity and carbon storage was confirmed in many other studies (e.g. Steinbeiss et al., 2008; Williams

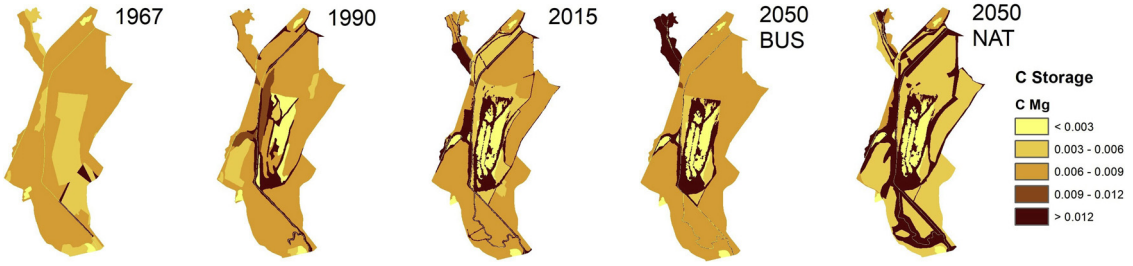

Fig. 4. Carbon Storage modeled in NRPB for the different dates and scenarios.

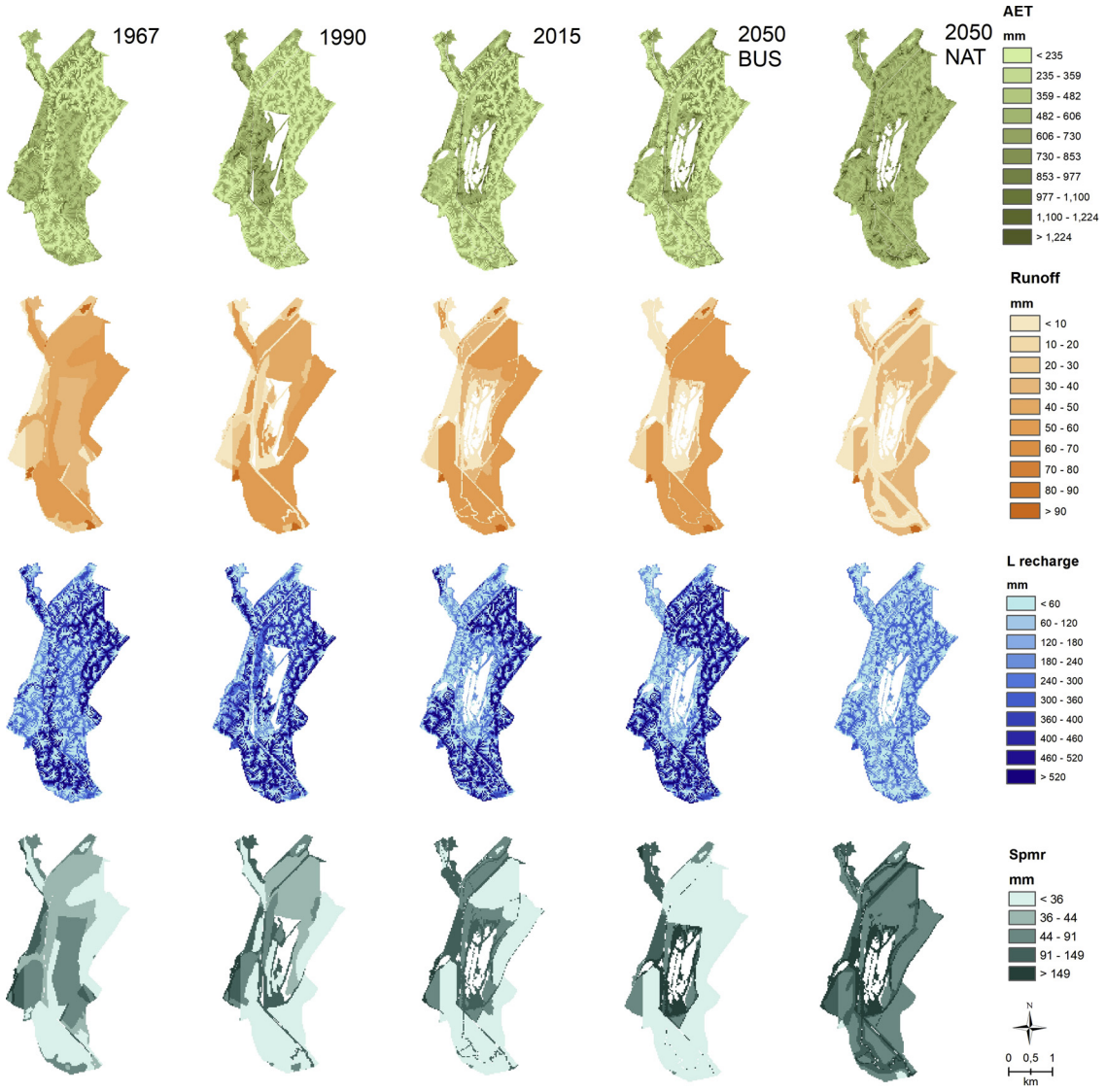

Fig. 5. Water budget components and *Spmr* modeled in NRPB for the different dates and scenarios (climate change is not considered).

Table 5
Modeled water budget and *Spmr* in NRPB. Values are expressed in mm.

	Recharge	Actual ET	Runoff	Spmr	Precipitation
1967	145.0	527.5	40.1	50.7	712.6
1990	139.5	537.8	35.3	58.9	712.6
2015	122.7	557.0	32.9	62.5	712.6
[1]2050 BUS	129.1	546.8	36.6	64.3	712.6
[1]2050 NAT	97.3	598.0	17.3	89.3	712.6
[2]2050 BUS	31.6	542.3	23.8	64.3	597.7
[2]2050 NAT	2.0	584.9	10.8	89.3	597.7

[1] Without considering climate change.
[2] Considering climate change.

et al., 2008; Hall et al., 2012; Peh et al., 2016; Vergílio et al., 2016), to such an extent that some high-biodiversity areas could be protected by carbon-based conservation strategies (Strassburg et al., 2010). Moreover, a relatively high overlap between carbon and soil-ESs was detected in literature (Izquierdo and Clark, 2012; Gissi et al., 2014; Gissi et al., 2018). For example, the carbon stored in aboveground biomass was positively correlated with both water supply and water regulation in Rodríguez et al. (2015). Flood prevention seems positively correlated with biodiversity conservation (Egoh et al., 2009; Newton et al., 2012) and carbon storage (Chan et al., 2006), even though correlations values are generally low. On the other hand, conservation efforts may lead to controversial outcomes. Castro et al. (2015) found that the higher levels of protection do not ensure the provision of multiple ESs. Fedrigotti et al. (2016) found that forest expansion at the expense of grasslands and croplands (i.e. renaturalization) in Alpine environments may reduce the economic contribution of ESs. Negative outcomes were also detected in deltaic environment (Gaglio et al., 2017a) and tropical mountain areas (García Márquez et al., 2017; Gaglio et al., 2017b). Izquierdo and Clark (2012) observed slight negative correlation between water yield and biodiversity, as well as with carbon storage.

This study demonstrated that conservation actions affected the ESs provision in the NRPB over time during 1967–2015, while the future designed LULC scenarios for 2050 with and without climate change effects revealed that management decisions have important effects on ESs supply. The ESs analysis highlighted that the efforts for biodiversity conservation through PAs can lead to parallel positive responses in terms of climate mitigation and flood prevention in floodplains such as NRPB. However, some conflicts may arise in water regulation services (Carvalho-Santos et al., 2016a,b). As indicated by Table 5, all the LULC conditions after 1965, including the future scenarios, led to reduction of recharge and runoff and increase of water retention, which is desirable for floodplains and vulnerable environments to floods in general. On

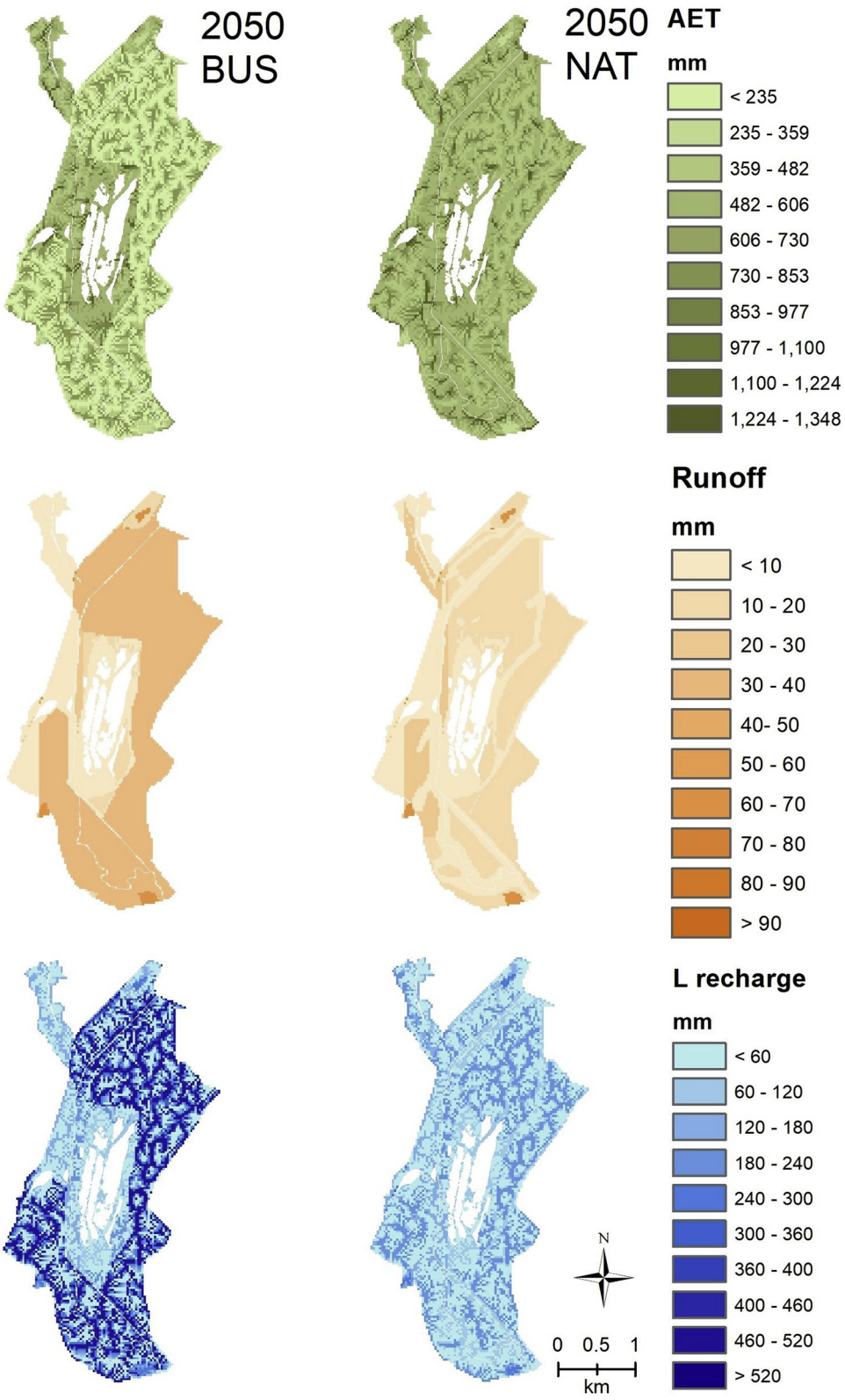

Fig. 6. Water budget components modeled in NRPB for the Business and Naturalization scenarios to 2050 considering climate change effects.

the other hand, respective LULC changes may have a negative impact in places where groundwater resources are limited or minimum ecological flows in surface waters are difficult to guarantee. These observations are in line with the findings of Quintas-Soriano et al. (2014), who described that non-protected areas are more relevant providers of groundwater recharge service in comparison to the protected landscapes. Conversely, the increase of real evapotranspiration due to the increase of water retention may boost the biomass production and consequently the provisioning services (e.g. food and timber production) counterbalancing the economic loss from water regulation services. On the other hand, even this pathway of ESs exploitation is not a secure plan since *AET* was slightly reduced in the of BUS and NAT

scenarios considering the climate change effects.

Overall, the analysis of ESs trends in NRPB revealed that the mere biodiversity conservation may not be effective in maintaining some ESs and that an active management is required. Future management of NRPB should consider the relationships among ESs raised in this analysis and the role of conservation strategies. If only biodiversity conservation is fostered (e.g. NAT scenario), the contribution of the Reserve to climate change mitigation and the capacity to buffer flooding will increase, though this would cause a decrease of water supply (especially if rcp85 will occur) with unpredictable consequences on the preservation of the aquatic environment. Contrarily, the maintenance of a limited extension of agricultural land and pastures on the NRPB, managed with non-intensive practices, could be an ecological solution to maintain a balanced water budget. This result is in line with the findings of Felipe-Lucia and Comin (2015), who demonstrated that a mosaic of different LULC types can support ESs and biodiversity in agricultural floodplains. In any case, the relevance of our study resides in make trade-offs between ESs explicit, in order to inform decision makers towards the potential consequences of different actions (Gissi and Garramone, 2018).

Special consideration should be given to the riparian ecosystems of NRPB. Particularly, mature riparian forest provide high values of evapotranspiration and *Spmr*, as well as carbon storage, soil conservation and nutrient retention (Dindaroğlu et al., 2015). On the other hand, such forest transitions in lowland areas may cause a dramatic decrease of local recharge capacity. Therefore, the management and regulation strategies concerning these ecosystems are fundamental for the provision of ESs at regional scale (Garrastazú et al., 2015; Sáenz et al., 2016; Vidal-Abarca et al., 2016).

As far as climate change is concerned, it was observed that decision making in land use will be challenging when considering future climate projections. When conservation measures included the total renaturing of the Reserve, the trade-off between water infiltration and flood prevention capacity results were exacerbated. These findings are confirmed also by other studies. In fact, increase of flood attenuation potential of floodplains under climate change was predicted also by Moor et al. (2015). Other studies carried out in Mediterranean basins evaluated that water supply service may be reduced up to 49% (Bangash et al., 2013) or almost 100% (Terrado et al., 2014).

4.2. Limitations of the modelling approach

Even though spatially explicit models are probably among the finest tools to map ESs provision, their application presents some limitations, generally related to both the reliability of input data and to the simplifications that lie under the assumptions on which models are based on (Bagstad et al., 2013; Hou et al., 2013). Moreover, when models are based on a low number of input parameters, their sensitivity to these factors can be high, especially when data is obtained from national inventories, which represent desirable sources when no field data is available. On the other hand, national inventory datasets may not capture adequately the variability in fine spatial scales.

Additionally, some model simplifications are necessary to be accepted when describing very complex phenomena, such as those that regulate ecological functioning. For instance, the “Carbon Storage and Sequestration” model assumes that none of the LULC types gains or loses carbon over time or under the effects of climate change. The only changes in carbon storage captured by the model over time are those due to changes from one LULC type to another. As suggested by InVEST 3.3.3 users ‘guide, this problem can be at least partially addressed classifying some LULC types into age classes, as it was made in this work. Similar problems have been observed in other studies (Bottalico et al., 2016). Moreover, the model does not include greenhouse gas emissions related to agricultural activities (e.g. tillage, fertilizer and pesticide applications) that affect the net carbon sequestration capacity of croplands and should be considered under a life cycle perspective.

Similar limitations appear also in the case of hydrological parameters (e.g. crop factors, soil hydrologic groups), which are necessary in the “Seasonal Water Yield” tool. Crop factors of the same crops/land uses, which are given in various databases (e.g. database of InVEST model or FAO), may differ significantly from place to place either due to local soil-climate conditions or due to different cultivation practices (Aschonitis et al., 2018). Additionally, in the case of soil hydrologic groups, it is not taken into account the evolution in soil conditions from the LULC changes.

5. Conclusions

The present study highlighted the relevance of conservation initiatives in ESs provision and the significance of modeling approaches for their explanation. The spatially explicit assessment of ESs using modeling approaches like InVEST can inform and support managers on environmental decisions considering trade-off between ESs that are strongly associated to the human well-being of local populations. From the results of the study, it was concluded that floodplain riparian habitats like NRPB display a high capacity for the delivery of multiple ESs. The limitation of human activities, such as agriculture and grazing, could be desirable to optimize the delivery of ESs, which are related to carbon and water retention. On the other hand, significant conflicts between specific water regulation services may appear by the application of PA initiatives. Possible reductions of water recharge to groundwaters and runoff, such as those observed in the specific study, may not be desirable in places where groundwater resources are limited or minimum ecological flows in surface waters are difficult to be maintained. Thus, the use of modeling approaches to assess complex ESs interactions, taking also into account the possible effects of climate change, can be a valuable tool for the description of ecological mechanisms that underlie trade-offs and synergies among ESs and for supporting decision making. This is particularly important when considering protected areas, where the assessment of the services delivered is urgently needed in order to provide arguments for biodiversity conservation.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ecolmodel.2019.04.019.

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